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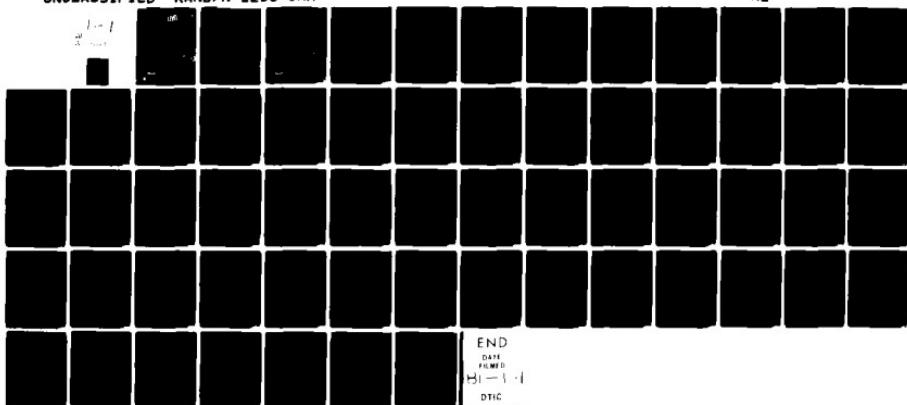
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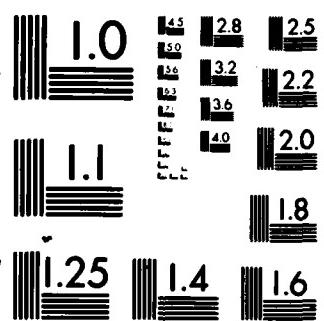
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DECISIONMAKING DURING THE PERSIAN GULF WAR

Barbara Hayes-Roth and Perry W. Williams

October 1980

N-1213-GNR

Prepared For

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(6) DECISIONMAKING DURING THE PLANNING PROCESS •

(10) Barbara Hayes-Roth and Perry W. Thorndyke

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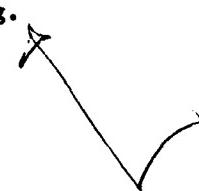
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Planning requires an individual to make a series of decisions about an intended course of action. This Note evaluates two major assumptions of an "opportunistic" model of the planning process: (a) that planners make decisions at different levels of abstraction; and (b) that prior decisions influence subsequent decisions opportunistically, regardless of their respective levels of abstraction. The results of three experiments support these assumptions. In Experiment 1, subjects sorted statements of different planning decisions according to similarity. A hierarchical clustering analysis of their sortings confirmed the postulated levels of abstraction. In Experiments 2 and 3, subjects chose between alternative decisions, given a particular prior decision. In Experiment 2, the prior decision influenced subjects' choices between two alternative decisions at both higher and lower levels of abstraction than the prior decision. In Experiment 3, it influenced their choices between alternatives at two different levels of abstraction. This Note should interest researchers concerned with cognitive processes underlying planning.



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PREFACE

This Note documents three experiments on decisionmaking during the planning process. It explicates the kinds of decisions planners make and the principles underlying the sequencing of decisions during planning. It should interest researchers concerned with cognitive processes underlying planning. The research was supported by Contract N00014-78-C-0039 from the Office of Naval Research.

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SUMMARY

Planning requires an individual to make a series of decisions about an intended course of action. This Note evaluates two major assumptions of an "opportunistic" model of the planning process: (a) that planners make decisions at different levels of abstraction; and (b) that prior decisions influence subsequent decisions opportunistically, regardless of their respective levels of abstraction. The results of three experiments support these assumptions. In Experiment 1, subjects sorted statements of different planning decisions according to similarity. A hierarchical clustering analysis of their sortings confirmed the postulated levels of abstraction. In Experiments 2 and 3, subjects chose between alternative decisions, given a particular prior decision. In Experiment 2, the prior decision influenced subjects' choices between two alternative decisions at both higher and lower levels of abstraction than the prior decision. In Experiment 3, it influenced their choices between alternatives at two different levels of abstraction.

ACKNOWLEDGMENTS

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I. INTRODUCTION

Planning is the formulation of an intended course of action. In a recent paper, Hayes-Roth and Hayes-Roth (1979) proposed an "opportunistic" model of the cognitive processes a person uses when planning. Two major assumptions of the model are that, in the course of planning, (a) planners make decisions at different levels of abstraction; and (b) prior decisions influence subsequent decisions opportunistically, regardless of their respective levels of abstraction.

These two assumptions distinguish the opportunistic model from other models of the planning process (Atwood & Polson, 1976; Byrne, 1977; Greeno, 1974; Jeffries, Polson, Razran, & Atwood, 1977; Newell & Simon, 1972; Newell, Shaw, & Simon, 1963; Sacerdoti, 1975). While many of the earlier models postulate the existence and functionality of levels of abstraction, they do not identify specific levels or operationalize the distinctions among them. These models also assume that planning is fundamentally a "top-down" process. That is, the planner initially formulates an abstract plan and successively refines it at lower levels of abstraction. In contrast, the opportunistic model operationalizes a particular set of levels and assumes that planning includes both top-down and bottom-up decision sequences.

This Note evaluates these two assumptions of the opportunistic model, using the results obtained in three experiments. In Experiment 1 we provide evidence for the psychological validity of the specific levels of abstraction postulated by the model. In Experiments 2 and 3 we demonstrate that during planning, a decision made at a particular level

of abstraction can influence subsequent decisions at both higher and lower levels of abstraction.

The remainder of the Note is organized as follows. We first describe an "errand-planning task" to illustrate the nature of the planning tasks under consideration and provide a context in which to present the opportunistic model. We then describe the opportunistic model and explain the two major assumptions introduced above in more detail. Finally, we report the three experiments performed to test the assumptions.

II. THE ERRAND-PLANNING TASK

In the Hayes-Roth and Hayes-Roth (1979) planning task, subjects had to formulate a plan for performing a set of errands in a fictional town (see Figure 1). Subjects read a scenario that described a list of desired errands, a starting time and location, an ending time and location, and sometimes some additional constraints. A simple example follows:

You have just parked your car at the Maple Street Parking Structure (56). The errands on your list are:

- > buy a shirt at Bruno's men's store (15)
- > buy a birthday card at the card and gift shop (37)
- > check out the rental listings at Century 21 (57)
- > buy some coffee mugs at Pier 1 (51)
- > buy some fish food at the pet store (23)

Because the allotted plan execution time was invariably insufficient to perform all of the errands, subjects had to decide which errands to perform as well as how to organize their activities. Subjects' complete plans specified: (a) what errands to perform, (b) how much time to spend performing individual errands, (c) the order in which to perform the errands, and (d) the routes to travel between errands.

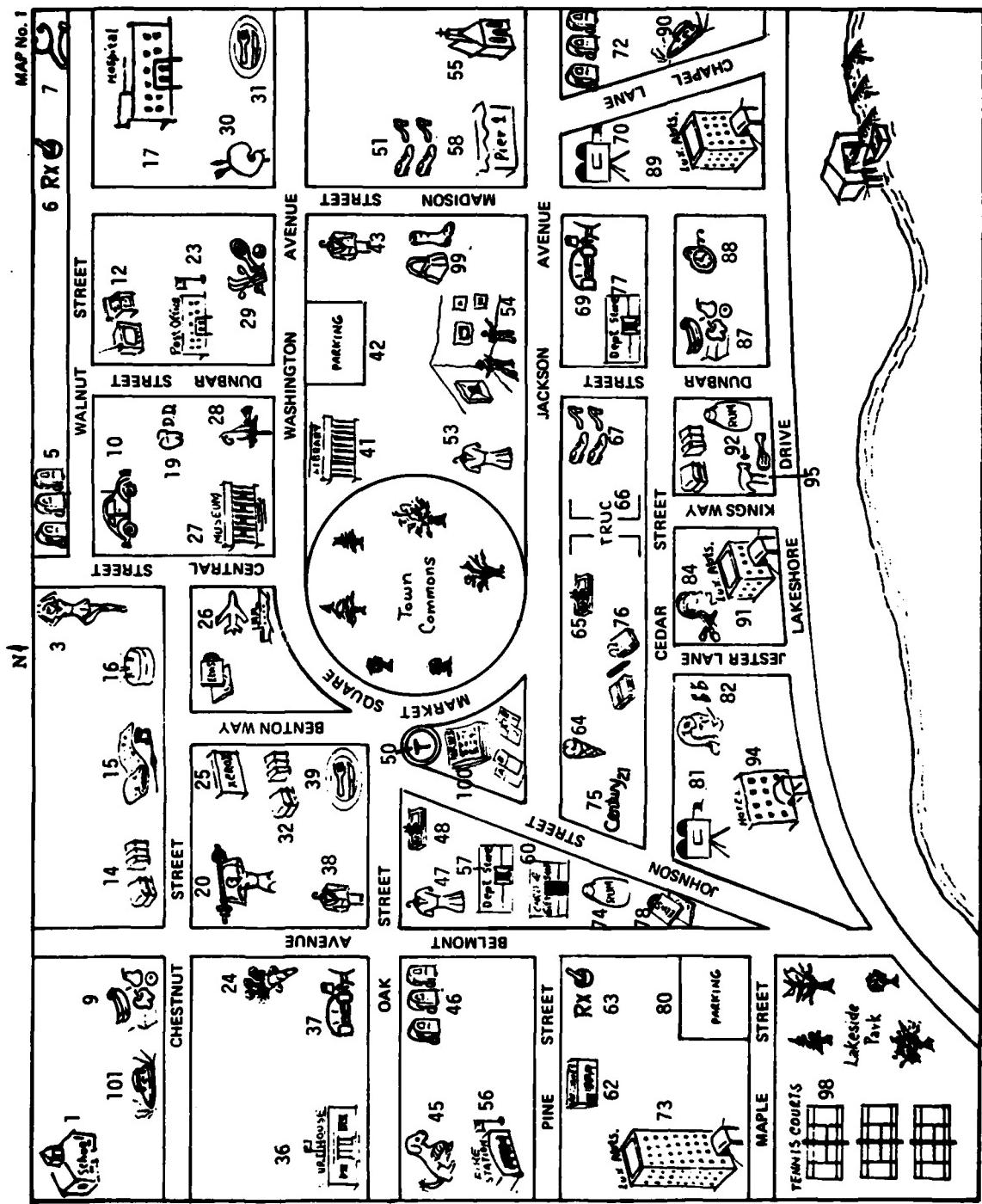


FIG. 1.—Map of the fictitious town used in Experiments 2 and 3

III. THE OPPORTUNISTIC PLANNING MODEL

The opportunistic planning model comprises three major components: a blackboard, or data base, on which individual decisions are posted during the planning process; a set of independent specialists that produce tentative decisions for incorporation into the developing plan; and an executive control structure to coordinate the activities of the specialists. In the following paragraphs we briefly describe each of these components.

The model assumes that decisions made during planning and posted on the blackboard are partitioned into categories defined by their levels of abstraction, or the amount of detail specified by a decision. High-level decisions specify only the most general characteristics of the final plan, while low-level decisions specify the details of individual planned actions. For the errand-planning task, Hayes-Roth and Hayes-Roth (1979) postulated four levels of abstraction: outcome, design, procedure, and operation. They operationalized these levels as follows:

1. Outcome decisions indicate an intention to perform a particular errand. They do not specify when to perform the errand (either in absolute terms or relative to the performance of some other errands) or the route by which to travel to the errand.

Example: I will definitely buy the birthday card today.

2. Design decisions provide a gross characterization of the temporal-spatial organization of the plan. They indicate a general time or order in which sets of errands will be performed but do not specify exact orderings of individual errands or specific routes between successive errands.

Example: I will do all of the errands on the west side of town before I do the errands on the east side of town.

3. Procedure decisions determine the order in which individual errands will be performed but do not specify routes between successive errands.

Example: I will go to the card and gift shop first.

4. Operation decisions determine the exact routes to be taken in performing the errands.

Example: I will travel from the Maple Street Parking Structure to the card and gift shop by walking north on Belmont Avenue.

(While the complete model postulates many other kinds of decisions, in this Note we restrict our attention to those described above.)

Decisions posted on the blackboard are produced by the planning specialists. Different specialists have different kinds of planning knowledge and influence different aspects of the plan. Some specialists suggest high-level additions to the plan (e.g., outcomes), while others suggest detailed sequences of specific actions (e.g., operations). Each specialist can examine prior decisions posted on the blackboard, transform or combine that information with its own knowledge, and generate new decisions. The model operationalizes specialists as condition-action rules, similar to the production rules of Newell and Simon (1972). For example, one specialist might embody the following heuristic:

IF there is a requested errand near the current location
THEN decide to perform that errand next.

As this example illustrates, a specialist's condition describes the circumstances under which it can contribute a decision to the plan. When the condition of a specialist has been satisfied, we say that the

specialist has been invoked. A specialist's action might be to post a new decision on the blackboard at a particular level of abstraction or to change a previous decision.

The model assumes that different specialists combine levels of abstraction in a variety of ways. For example, some specialists operate "top-down." That is, they require prior decisions at relatively high levels of abstraction and post new decisions at lower levels. To illustrate, the following specialist requires as a condition a prior design decision, while its action posts a new procedure decision:

IF the design is to do all the errands on the east side of town first
AND there are some unplanned errands on the east side of town
THEN do an unplanned errand on the east side of town next.

Conversely, some specialists operate "bottom-up." They require prior decisions at relatively low levels of abstraction and post new decisions at higher levels. The following specialist requires a prior operation decision, while its action posts a new procedure decision:

IF there is a shortcut connecting two unplanned errands
THEN do the two errands consecutively.

The model assumes that planning proceeds through a series of cycles during which specialists read information from the blackboard and execute their actions. On any cycle, a number of specialists may be invoked--that is, their conditions may have been satisfied by the appearance of some prior decision on the blackboard. An executive decision selects one of the invoked specialists to execute its action,

generating a new decision and recording it on the blackboard. This new decision will invoke additional specialists, beginning a new cycle. The process will ordinarily continue until the planner has integrated mutually consistent individual decisions into a satisfactory overall plan.

The scheduling of invoked specialists is an important feature of the model. It is assumed to be an opportunistic process. This means that there is no strong a priori organization of planning activity. Instead, the executive schedules the most desirable of the currently invoked specialists. Desirability may reflect consideration of a number of factors, such as recency of invocation, ability to contribute a particular kind of decision to the plan, ability to contribute a decision at a particular level of abstraction, etc.

We can now restate the two assumptions under investigation in terms of the details of the model.

LEVELS OF ABSTRACTION

The model identifies and operationalizes four levels of abstraction for the errand-planning task: outcome, design, operation, and procedure. We assume that planners make decisions at each of these levels of abstraction and that the levels have "psychological significance." Hayes-Roth and Hayes-Roth (1979) presented informal support for this assumption in the thinking-aloud protocols produced by their subjects. The protocols contained many instances of decisions representing each of the four postulated levels of abstraction. However, two factors limit the utility of these results. First, the results are observational and do not provide an experimental test of the assumption. Second, although

the results demonstrate the descriptive value of the postulated levels of abstraction, they do not show that the levels have any special significance from the subject's point of view. Experiment 1 provides an experimental test of the psychological significance of the postulated levels of abstraction.

OPPORTUNISM

The model provides two underlying mechanisms for opportunism. First, it assumes that there exist both top-down and bottom-up planning specialists. This provides an explicit capability for prior decisions to influence the generation of subsequent decisions at both higher and lower levels of abstraction. Second, the model assumes that the executive control process is, itself, opportunistic. By using a variety of criteria to schedule invoked planning specialists, the executive permits a variety of overall organizations of the planning process.

Hayes-Roth and Hayes-Roth (1979) also provided informal support for the opportunism assumption in the thinking-aloud protocols they described. The protocols contained many decision sequences illustrating both top-down and bottom-up progressions. Again, while these results are provocative, they do not provide a strong test of the assumption. Temporal contiguity of related decisions in a protocol suggests but does not imply that the prior decision influenced the generation of the subsequent decision. Experiments 2 and 3 provide direct tests of this assumption for both top-down and bottom-up progressions.

IV. EXPERIMENT 1

If the postulated levels of abstraction--outcome, design, procedure, and operation--represent distinct cognitive categories of planning decisions, then even people unfamiliar with the theory should recognize the similarities among decisions within a level and the differences among decisions from different levels. In particular, if asked to cluster decisions by similarity, subjects should group decisions from a particular level together. Experiment 1 tested this prediction.

The materials for this experiment comprised statements taken directly from thinking-aloud protocols of subjects performing the errand-planning task. We selected statements representing decisions at the four levels of abstraction. Then we presented the statements to theoretically naive subjects in a sorting task. These subjects ordered the statements in a sequence so that statements close together in the sequence "communicated similar kinds of information," while statements further apart "communicated different kinds of information."

We then submitted subjects' orderings to a hierarchical clustering analysis. We predicted that statements representing each level of abstraction should cluster together. Alternatively, subjects might order statements on the basis of extraneous features, such as reference to a common street or errand, syntactic structure of the statements, temporal reference, etc. This might produce reliable clusters, different from those predicted by the theory. Subjects also might not produce reliable clusters at all. This would occur if subjects did not

notice similarities among statements or if different subjects focused on different similarities.

METHOD

Materials. We drew sixteen statements from thirty thinking-aloud protocols (six protocols obtained from each of five subjects). Four statements represented each of the four levels of abstraction (see Table 1). We tried to select statements that varied in content as much as possible within each level. In addition, we attempted to minimize correlations between the predicted categories and obvious linguistic cues, including sentence length, number of clauses, number of nouns, and number of concrete nouns. Finally, we did not include any statements that instantiated other statements at higher levels of abstraction. We also excluded statements from a single protocol that were obviously related. Thus, no explicit or implicit relationships between statements cued subjects to use the predicted categorization.

Procedure. Subjects were tested in groups. The experimenter gave each subject sixteen cards, with one statement typed on each card. Subjects were instructed to order the cards in a line, so that statements close together in the line "communicated similar kinds of information," while statements far apart in the line "communicated different kinds of information." Each card had a randomly assigned number between one and sixteen printed on the back.

After ordering the statements, subjects turned over the cards and recorded the card numbers in sequence on an answer sheet. Subjects then performed a distractor task requiring them to mark all articles in a

Table 1

STATEMENTS FROM THE FOUR LEVELS OF ABSTRACTION
USED IN THE SORTING TASK IN EXPERIMENT 1

Outcomes

1. The main thing I've got to do today is a dentist appointment.
2. Signing the papers at my lawyer's office is something I have to get done.
3. I'll try to pick up the package at the post office.
4. So I have to buy ice cream.

Designs

5. I'm going to do errands that are in the northwest part of town.
6. I'm on the south side of town, so I thought it would be a good idea to make a northerly sweep.
7. I've got two sort of general areas that I'm working with, one that has the parking garage, the tennis court, and the drugstore, and one that has the museum.
8. I think I'll go around in a circle.

Procedures

9. I'm going to go from the sporting goods store to the subway station.
10. I can go to the travel agency last before I go to the subway station.
11. I could just whip on down to the art supply store after I go to the museum.
12. I'll leave the music place and go over to the bookstore on Cedar Street.

Operations

13. I'll go down Central, through the park, onto Jackson, down Johnson Street, through the park, and to the tennis courts.
14. I'll go down Cedar to Dunbar, to Lakeshore, into King's Way, to the hardware store.
15. I'll go up Belmont, onto Pine Street to the pharmacy.
16. I then proceed due east on Pine, north on Belmont, and then west on Oak to the courthouse to pay the traffic ticket.

five-hundred word text. This task lasted approximately five minutes. Subjects then performed the sorting task again, beginning with a new random ordering of the sixteen statements. Subjects performed these two tasks alternately until they had performed the sorting task four times in all.

Subjects used new answer sheets on each trial, so that no record of previous orderings could influence subsequent orderings. In addition, we instructed subjects not to strive for consistency in their orderings across trials, but rather to give an "honest," independent ordering of the statements on each trial.

Subjects. Eleven UCLA undergraduates participated as subjects.

RESULTS AND DISCUSSION

We submitted the data to Friendly's (1977) hierarchical clustering program. This program identifies clusters based on pairwise item proximities in the sequences subjects produced. The program first computed average proximities between all 120 pairs of statements across the forty-four constructed sequences (four sequences for each of eleven subjects). It defined "proximity" as list length (sixteen) minus the average number of other statements intervening between a given pair. Thus, a large proximity value indicates a pair of statements that subjects tend to place near one another in their orderings, that is, statements that subjects believe communicate similar kinds of information. The program used these proximities to join the statements recursively into clusters. It began by joining the pair of statements with the largest proximity into a cluster. On subsequent "cycles," it joined additional

statements to one another or to existing clusters in order of decreasing proximity. The program treated existing clusters as units, measuring the proximity of a statement to a cluster as its proximity to the most proximate member of the cluster (the "single link" or "nearest neighbor" method). (See Friendly (1977) for a more detailed account of this methodology.)

The clustering analysis described above provides a direct test of the hypothesis that the four postulated levels of abstraction represent a salient dimension of psychological similarity. As discussed above, subjects might reasonably recognize other dimensions of similarity among the sixteen statements they sorted. These, along with the predicted abstraction dimension, might define a multidimensional psychological space. By forcing our subjects to produce a linear ordering of the statements, we have provided a rigorous test of the hypothesis. Confirmation requires not only that abstraction constitute a psychologically valid dimension of psychological similarity, but that it also be prominent enough to dominate the several other dimensions of similarity.

Figure 2 shows the results of the clustering analysis. Statement numbers on the left side of Figure 2 correspond to the statement numbers in Table 1. For brevity, we have labeled groups of statements with their theoretical levels of abstraction.

Figure 2 shows the normalized proximity values (proportions of the maximum possible proximity value) at which the program joined individual statements and clusters into larger clusters. For example, the program joined outcomes 1 and 2 first, at the maximal proximity, 1.0. It joined

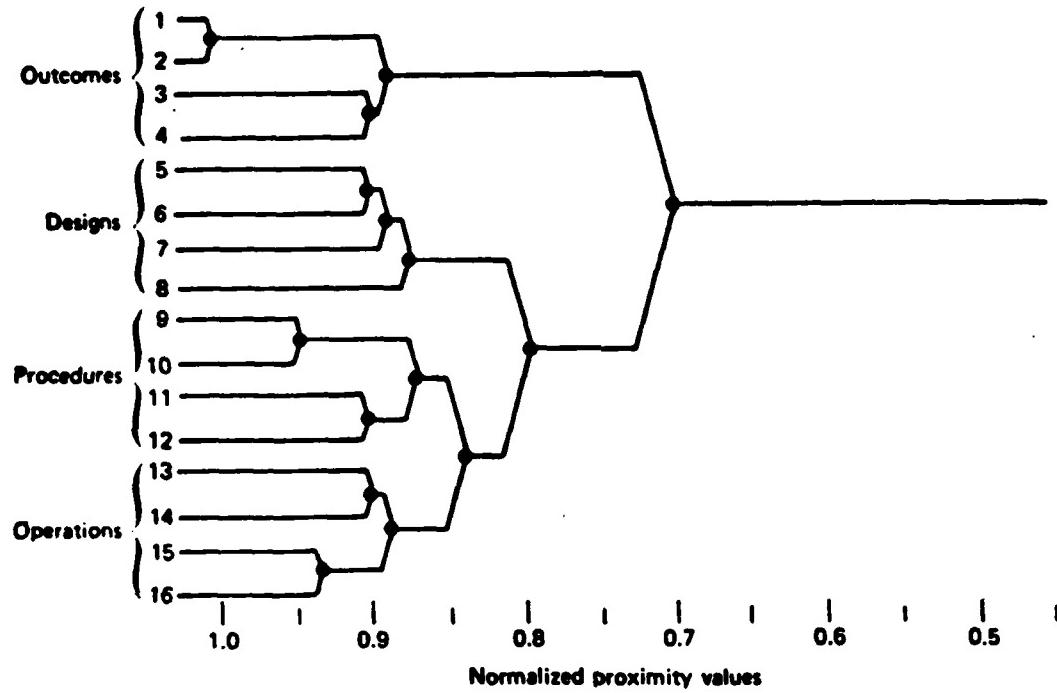


Fig. 2--Clusters formed in the hierarchical analysis of subjects' similarity orderings of planning statements

outcomes 3 and 4 at proximity .89 and immediately merged the two clusters of outcomes into a single cluster.

As shown in Figure 2, subjects closely grouped the four statements representing each level of abstraction. The program formed all four predicted clusters at proximities of .87 or higher. It did not form clusters across different levels of abstraction until all statements within a level were merged into a single cluster. Further, the analysis combined higher-order clusters in the same order specified by the

abstraction hierarchy. In Figure 2, statements on the edge of each cluster border the most proximate statements from different clusters. For example, of non-outcome statements (5-16), design 5 is the most proximate to outcome 4. These between-cluster proximities ordered the level clusters from most abstract (outcomes) to least abstract (operations).

These results confirm the postulated levels of abstraction. Subjects recognized that statements within a level communicated similar kinds of information, that statements from different levels communicated different kinds of information, and that statements from adjacent levels were more similar than statements from non-adjacent levels. Thus, the postulated levels of abstraction appear to represent functional cognitive categories for planning decisions.

V. EXPERIMENT 2

The second major assumption to be tested is that early planning decisions influence subsequent decisions opportunistically, regardless of their relative levels of abstraction. As discussed above, it is difficult to test this prediction in a spontaneous planning paradigm. Temporal contiguity of two decisions in a protocol does not imply a causal relationship in their generation. Therefore, in Experiment 2, we modified the planning task to enable us to control the generation of early decisions and to predict the generation of subsequent decisions.

We modified the planning task as follows. We gave subjects a series of planning problems. In addition to the usual problem statement, as described above, each problem included a constraint specifying a particular prior decision. For example, one problem included the constraint that the subject plan to go to the drugstore first. Then, instead of forming a complete plan, subjects chose one of two alternative subsequent decisions. For example, the subject might choose between two alternative routes to the drugstore. In all problems, subjects could reasonably choose either of the two alternative decisions. Half of the problems tested for a top-down influence; that is, the prior decision was at a higher level of abstraction than the two alternative subsequent decisions in these problems. The other half of the problems tested for a bottom-up influence; the prior decision was at a lower level of abstraction than the two alternatives.

Under the opportunism assumption, a subject's choice between alternative decisions should be influenced by the particular prior decisions

the subject has made at both higher and lower levels of abstraction. Therefore, by constraining subjects to make particular prior decisions, we should be able to influence their tendency to choose between alternative subsequent decisions. Further, we should be able to influence subjects' decision sequences in both top-down and bottom-up directions.

In top-down problems, subjects should tend to choose subsequent decisions that fill in the details of prior higher-level decisions. The following problem illustrates this prediction. It constrains the subject to make a particular design decision and to choose a subsequent procedure decision.

You have just parked your car at the Maple Street Parking Structure (56). The errands on your list are:

- > buy a shirt at Bruno's men store (15)
- > buy a birthday card at the card and gift shop (37)
- > check out the rental listings at Century 21 (57)
- > buy some coffee mugs at Pier 1 (51)
- > buy some fish food at the pet store

You've decided to make a circle around town, doing each errand as you come to it. After leaving the parking structure, will you go:

- (a) to the men's store and then to the card and gift shop?
- (b) to the card and gift shop and then to the men's store?

For this example, decision (b) fills in some procedure-level details of the prior design decision. Proceeding from the parking structure to the

card and gift shop and then to Bruno's men's store will provide an efficient realization of the plan to make a circle around town. Decision (a), on the other hand, represents a reasonable partial plan but does not elaborate the prior design decision. While the subject could go to Bruno's before the card and gift shop and still make a circle around town, this would not be a very efficient realization of that design. We presume that efficiency is one of the general criteria most subjects bring to bear during planning. Therefore, for this example, subjects should tend to choose decision (b).

Alternatively, the problem might constrain subjects to make the following design decision:

You've decided to do all of the errands on the west side of town before doing any of the errands on the east side of town.

In this case, decision (a) provides a more efficient procedure-level realization of the design than decision (b). The route from the parking structure up Belmont Avenue to Bruno's, back down Belmont Avenue to the card and gift shop, and then across Johnson Street to Century 21 is the shortest route accomplishing all three errands on the west side of town. Again, while the subject could choose decision (b) and still carry out the prior design, this would not be a very efficient realization of that design. Therefore, for this example, subjects should tend to choose decision (a).

In the case of bottom-up problems, subjects should tend to choose subsequent decisions that incorporate the details of constraints on prior lower-level decisions. The following problem illustrates this

prediction. It uses the same errand list as the top-down problems above. However, it constrains the subject to make a particular procedure decision and to choose a subsequent design decision:

You've decided to go directly from the parking structure to the card and gift store and then to the men's store. Will you:

- (a) do all of the errands on the west side before doing those on the east side?
- (b) continue in a circle around town, doing each errand as you come to it?

For this example, design decision (b) incorporates the details of the prior procedure decision. Again, the subject could reasonably choose either of the two alternatives. However, given that the subject has decided to go to the card and gift shop before going to Bruno's men's store, the circle design is more efficient than the west side-east side design. Therefore, subjects should tend to choose decision (b).

Alternatively, the problem might constrain subjects to make the following decision:

You've decided to go directly from the parking structure to the men's store and then to the card and gift shop.

In this case, design decision (a) incorporates the details of the prior procedure decision more effectively than decision (b). Going to the men's store first and then returning to the card and gift shop is more suggestive of a design that clusters errands on each side of town than of a circle design. Therefore, subjects should tend to choose decision (a).

Of course, factors other than prior decisions and efficiency might influence subjects' choices of subsequent decisions. In addition, subjects may differ in their perceptions of the relative "efficiency" of two alternative decisions. Therefore, constraining subjects to make particular prior decisions may not completely determine their selection of subsequent decisions. However, the opportunism assumption predicts that constraints on prior decisions should influence subjects' tendency to select one or the other. Experiment 2 tests this prediction.

METHOD

Materials. The examples given above illustrate the problems used in this experiment. Each problem prototype included a list of desired errands, starting and ending times and locations, and two alternative decisions at each of two levels of abstraction. We generated four test items from each prototype. Two of the items presented top-down decision sequences. Each of these items constrained subjects to make one of the higher-level decisions and to select one of the two alternative lower-level decisions. As in the example above, each alternative was predicted for one of the prior decisions. The other two items presented bottom-up decision sequences. Each of these items constrained subjects to make one of the lower-level decisions and to select one of the two alternative higher-level decisions. Again, each alternative was predicted for one of the prior decisions. These materials enabled us to use essentially the same test items for both top-down and bottom-up analyses. For all items, both alternatives were plausible decisions; however, given a particular prior decision, one alternative led to a more

efficient plan. There were twelve problem prototypes in all, two for each pair of abstraction levels (outcome-design, outcome-procedure, outcome-operation, design-procedure, design-operation, procedure-operation). Thus, there were forty-eight test items in all.

Procedure. Subjects were tested in groups. They worked at their own pace through booklets containing the forty-eight test items in random order. After reading a problem and consulting the map shown in Figure 1, subjects indicated which of the two alternative decisions they would make. Subjects required between one and two hours to complete the task.

RESULTS AND DISCUSSION

To facilitate the discussion of results, we will refer to the alternative prior decisions for a given test item as A and B. We will refer to the alternative subsequent decisions as a and b. These alternatives are yoked such that, under the logic discussed above, prior decision A should incline subjects to choose subsequent decision a and prior decision B should incline subjects to choose subsequent decision b.

We computed two scores for each problem prototype: a top-down effect and a bottom-up effect. We computed each score as the difference in conditional probability of selecting response a, given the two alternative prior decisions. That is, the effect of a prior decision on the choice of a subsequent decision was $P(a/A) - P(a/B)$. Thus, the top-down effect measures subjects' preferences for decisions that efficiently instantiate prior higher-level decisions. The bottom-up effect measures subjects' preferences for decisions that efficiently incorporate the

details of prior lower-level decisions. In both cases, a score of zero indicates that the prior decision had no effect on subjects' choices of subsequent decisions. A score of one indicates that the prior decision completely determined subjects' choices of subsequent decisions. As discussed above, the model predicts that both effects should be greater than zero.

Table 2 shows the scores for top-down and bottom-up versions of each of the twelve problem prototypes. Averaging across levels of abstraction, the mean top-down effect, .62, is significantly greater than zero, $t(11) = 9.91, p < .001$. The mean bottom-up effect, .62, is also significantly greater than zero, $t(11) = 8.92, p < .001$. The magnitudes of these effects suggest that while prior decisions do not completely determine subsequent decisions, they have a substantial impact. In addition, top-down and bottom-up effects appear equally prominent. Thus, the results confirm the prediction and support the assumption that planning includes both top-down and bottom-up decision processes.

Table 2
TOP-DOWN AND BOTTOM-UP EFFECTS OF CONSTRAINT

Task	Effect	
	Top-Down	Bottom-Up
Outcome-Design 1	.75	.38
Outcome-Design 2	.63	.38
Outcome-Procedure 1	.75	.38
Outcome-Procedure 2	.63	.50
Outcome-Operation 1	.75	.88
Outcome-Operation 2	.63	1.00
Design-Procedure 1	.25	.38
Design-Procedure 2	.63	.50
Design-Operation 1	.88	.63
Design-Operation 2	.63	.75
Procedure-Operation 1	.13	.63
Procedure-Operation 2	.75	1.00
Mean	.62	.62

VI. EXPERIMENT 3

As discussed above, the opportunistic model assumes that prior decisions suggest unanticipated opportunities for plan development. Planners presumably exploit many of these opportunities regardless of the level of abstraction at which they occur. That is, they exploit suggested opportunities to develop the plan in progress at both higher and lower levels of abstraction than the level at which the prior decision occurred. Thus planning can be a "multidirectional" process.

Under this assumption, requiring subjects to make particular decisions early in the planning process should influence the level at which their subsequent decisions occur. For example, requiring a particular design decision might suggest a subsequent procedure decision, while requiring another design decision might suggest a subsequent outcome decision. By constraining subjects to make particular prior decisions, we should be able to influence their tendency to choose between alternative subsequent decisions at higher or lower levels of abstraction. Experiment 3 tested this predicted multidirectionality in the planning process.

The problems for Experiment 3 were similar to those described above for Experiment 2. Each problem constrained subjects to make a particular prior decision and to select one of two alternative subsequent decisions. However, for Experiment 3, one alternative represented the level of abstraction just above the level of the prior decision, while the other represented the level just below it. Thus, for a given prior

decision, the subject's choice of a subsequent decision defined either a top-down sequence or a bottom-up sequence.

The problem below illustrates the materials for Experiment 3. It constrains subjects to make a particular procedure decision and then to select either a design or an operation decision.

You're at the Washington Avenue parking lot (46) and want to do some errands before going home. Here are the errands you want to do:

- > look at new dresses at La Mode dress shop (45)
- > view the new exhibit at the art gallery (47)
- > look at boots at the leather goods store (49)
- > browse through Pier 1 (51)
- > stop and browse at the rummage sale at the Jackson Avenue Presbyterian church (52)
- > get a hair trim at the hair dresser (74)

You've decided to go to the hair dresser (74) right after going to the dress shop (45).

Will you:

- (a) Travel from east to west through town, doing each errand as you get to it?
- (b) Cut through the Truc (61)?

For this problem, decision (b) provides an extremely efficient route for traveling from the dress shop to the hair dresser. Decision (a), on the other hand, is largely independent of the prior decision. The subject could reasonably adopt the design specified in decision (a), but it is not particularly salient in light of the prior decision. Therefore, for

this problem, subjects should choose alternative (b), implementing a top-down decision sequence.

Alternatively, the same problem might constrain subjects to make the following prior decision:

You've decided to go to the rummage sale (52) after leaving the parking lot.

For this problem, alternative (a) is an obvious general design for the plan that gracefully incorporates the decision to go to the rummage sale immediately after leaving the parking lot. Decision (b), on the other hand, is largely independent of the prior decision. The subject might eventually decide to cut through the Truc, but that shortcut is not particularly salient in light of the prior decision. Therefore, for this problem, subjects should tend to choose alternative (a), implementing a bottom-up decision sequence.

As these examples illustrate, the opportunism assumption predicts that constraining subjects to make particular prior decisions should influence the selection of subsequent decisions at either higher or lower levels of abstraction. While factors other than prior decisions might also influence subjects' choices, constraints on prior decisions should influence their tendency to work top-down or bottom-up.

METHOD

Materials. The examples given above illustrate the problems used in this experiment. Each problem prototype included a list of desired errands, starting and ending times and locations, two alternative prior decisions, and two alternative subsequent decisions. There were two

groups of problem prototypes: those that specified a prior design decision and those that specified a prior procedure decision. There were six prototypes in each group.

For each problem prototype, one alternative subsequent decision was one level above that of the prior decision and the other alternative was at the level below. We constructed three test items from each prototype: one for each of the alternative prior decisions and one specifying no prior decision. (Test items specifying no prior decision served as controls, measuring subjects' predispositions to select one or the other of the two alternatives.) Alternatives (a) and (b) represented top-down and bottom-up progressions equally often. For all items, both alternative subsequent decisions were plausible selections. However, as discussed above, each prior decision was predicted to incline subjects to select one or the other of the alternatives. These materials permitted us to use essentially the same items for both top-down and bottom-up analyses.

Given two groups of six problem prototypes and three test items per prototype, there were thirty-six test items in all.

Procedure. Subjects were tested in groups. They worked at their own pace through booklets containing the thirty-six test items in random order. After reading each problem and consulting the map shown in Figure 1, subjects indicated which of the two alternative decisions they preferred. Subjects required about one hour to complete the experiment.

Subjects. Fifteen UCLA undergraduates served as subjects.

RESULTS AND DISCUSSION

To facilitate this discussion, we will designate any particular prior decision for a given task as D and no prior decision (the control condition) as C. We will refer to the alternative subsequent decision predicted to follow prior decision D as d.

We computed two scores for each problem prototype: a top-down effect and a bottom-up effect. We computed each score as $P(d/D) - P(d/C)$. Thus, the top-down effect measures the increase in subjects' a priori preferences for decisions when those decisions fill in the details of prior decisions. The bottom-up effect measures the increase in subjects' a priori preferences for decisions when those decisions reflect more general plan characteristics suggested by prior decisions. In both cases, a score of zero indicates that the prior decision had no effect on subjects' choices of subsequent decisions. A score greater than zero indicates that the prior score influenced subjects' choices of subsequent decisions. As discussed above, the opportunism assumption predicts that both scores should be greater than zero.

Table 3 shows the magnitudes of the top-down and bottom-up effects for each of the twelve problem prototypes. The mean top-down effect, .28, was significantly greater than zero, $t(11) = 5.50$, $p < .001$. The mean bottom-up effect, .09, was also significantly greater than zero, $t(11) = 2.40$, $p < .025$. Thus, the results confirm the prediction and support the assumption that planning includes both top-down and bottom-up processes.

Table 3

TOP-DOWN AND BOTTOM-UP EFFECTS OF
OPPORTUNISM IN EXPERIMENT 3

Task	Effect	
	Top-Down	Bottom-Up
Prior Decision at Design Level		
1	.27	.13
2	.13	-.13
3	.27	.00
4	.20	-.07
5	.13	.13
6	.60	.07
Prior Decision at Procedure Level		
7	.00	.20
8	.53	.07
9	.20	.33
10	.40	.20
11	.20	.13
12	.40	.00
Mean	.28	.09

The top-down and bottom-up effects observed in this experiment are considerably smaller than the corresponding effects observed in Experiment 2. In addition, in Experiment 3, the top-down effect appears larger than the bottom-up effect. (In Experiment 2, the effects were comparable for the two conditions.) These apparent differences between the results of the two experiments are probably artifacts of the different statistical techniques used in the two experiments. In both experiments, our measurement of each effect contrasted subjects' tendencies to choose a particular decision, given alternative prior decisions. In Experiment 2, we contrasted a case in which the prior decision motivated one choice with a case in which a different prior decision motivated the alternative. In Experiment 3, we contrasted a case in which the prior decision motivated one choice with a control case that motivated neither alternative. Thus, other factors being equal, we would expect the measurement in Experiment 2 to produce larger differences than the measurement in Experiment 3.

Note also that in Experiment 3, top-down and bottom-up statistics are not independent. The control condition, used to correct for response bias, provides complementary probabilities for the two problem types. For example, if the control probability is .4 for a top-down problem, it is .6 for the corresponding bottom-up problem. As these probabilities deviate from .5, they have opposite effects on the power of the statistics measuring the two effects. In general, it is easier to detect a significant increase in a smaller control probability than in a larger one. Thus, the dependence between the two statistics makes it more difficult to confirm the prediction that both top-down and

bottom-up effects should be significant. In fact, the mean control probabilities were .41 for top-down alternatives and .59 for bottom-up alternatives. This probably accounts for much of the apparent difference in the magnitudes of these two effects.

The important result of Experiment 3 is that both top-down and bottom-up effects occur. Some prior decisions suggest decisions regarding more general aspects of plan development. Others suggest particularly efficient instantiations.

VII. CONCLUSIONS

The results of the three experiments reported in this Note support two major assumptions of the opportunistic model: (a) that planners make decisions at four distinct levels of abstraction; and (b) that early decisions influence the generation of subsequent decisions at both higher and lower levels of abstraction.

We acknowledge that the tasks used in the present experiments differed markedly from natural planning tasks. These differences might have influenced our results. For example, while subjects recognized the levels of abstraction implicit in a set of decisions, they may not use these levels consciously or unconsciously when they are actually making decisions. Similarly, while subjects responded to imposed prior decisions in a forced-choice situation, they may not exhibit corresponding regularities when they make each decision in the sequence spontaneously. These differences between the studied tasks and natural planning activity must constrain our interpretation of the results.

On the other hand, testing the present hypotheses in a natural planning task also presents difficulties. Hayes-Roth and Hayes-Roth (1979) documented the occurrence of decisions representing each postulated level of abstraction in subjects' thinking-aloud protocols. However, that methodology does not permit assessment of subjects' awareness of the levels of abstraction or of the roles they play in the planning process. Hayes-Roth and Hayes-Roth also observed sequences of decisions in which high-level decisions preceded lower-level decisions that elaborated

them and vice versa. However, the mere occurrence of such sequences does not imply the postulated causal relationship.

Despite the limitations of each of these methodologies, the results from both types of studies confirm important predictions of the opportunistic model, thereby providing some support for it. The consistency of results from both methodologies further improves the model's credibility.

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DEPARTMENT OF THE NAVY

- 1 Mervil S. Baker
NPPRIC
Code P309
San Diego, CA 92152
- 2 Mr. Robert Breaux
Code E-711
NAVTABEQUIPCEN
Orlando, FL 32813
- 3 Chief of Naval Education & Training
Liason Office
Air Force Human Resource Laboratory
Flying Training Division
Williams AFB, AZ 85224
- 4 Dr. Richard Elster
Department of Administrative
Sciences
Naval Postgraduate School
Monterey, CA 93940
- 5 Dr. Pat Federico
Navy Personnel R&D Center
San Diego, CA 92152
- 6 Dr. John Ford
Navy Personnel R&D Center
San Diego, CA 92152
- 7 LT Steven D. Harris, MSC, USN
Code 6021
Naval Air Development Center
Warminster, Pennsylvania 18974
- 8 CDR Charles W. Hutchins
Naval Air Systems Command HQ
AIA-340F
Navy Department
Washington, DC 20361
- 9 Dr. Norman J. Kerr
Chief of Naval Technical Training
Naval Air Station Memphis (75)
Millington, TN 38054 Navy

- 10 Dr. William L. Maloy
Principal Civilian Advisor for
Education and Training
Naval Training Command, Code 00A
Pensacola, FL 32508
- 11 Dr. Kneale Marshall
Scientific Advisor to DCNO(NPT)
CPOIT
Washington DC 20370
- 12 CAPT Richard L. Martin, USN
Prospective Commanding Officer
USS Carl Vinson (CVN-70)
Newport News Shipbuilding and
Drydock Co
Newport News, VA 23607
- 13 Dr. William Montague
Navy Personnel R&D Center
San Diego, CA 92152
- 14 Commanding Officer
U.S. Naval Amphibious School
Coronado, CA 92155
- 15 Naval Medical R&D Command
Code 44
National Naval Medical Center
Bethesda, MD 20014
- 16 Ted S. I. Yellen
Technical Information Office,
Code 201
Navy Personnel R&D Center
SAN DIEGO, CA 92152
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Navy Personnel R&D Center
San Diego, CA 92152
- 18 Technical Director
Navy Personnel R&D Center
San Diego, CA 92152
- 19 Commanding Officer
Naval Research Laboratory
Code 2627
Washington, DC 20390

- 20 Psychologist
ONB Branch Office
Bldg 114, Section D
666 Summer Street
Boston, MA 02210
- 21 Psychologist
ONB Branch Office
536 S. Clark Street
Chicago, IL 60605
- 22 Office of Naval Research
Code 437
800 N. Quincy Street
Arlington, VA 22217
- 23 Personnel & Training Research
Programs
(Code 458)
Office of Naval Research
Arlington, VA 22217 5
- 24 Psychologist
ONB Branch Office
1030 East Green Street
Pasadena, CA 91101
- 25 Office, Chief of Naval Operations
Research, Development, and Studies
Branch (OP-102)
Washington, DC 20350
- 26 Captain Donald P. Parker, USN
Commanding Officer
Navy Personnel R&D Center
San Diego, CA 92152
- 27 LT Frank C. Petto, MSC, USN (Ph.D)
Code L51
Naval Aerospace Medical Research
Laboratory
Pensacola, FL 32508
- 28 Dr. Gary Poock
Operations Research Department
Code 55PK
Naval Postgraduate School
Monterey, CA 93940

- 29 Mr. Arnold Rubenstein
Naval Personnel Support Technology
Naval Material Command (08T244)
Room 1044, Crystal Plaza #5
2221 Jefferson Davis Highway
Arlington, VA 20360
- 30 Lt. Worth Scanland
Chief of Naval Education and Training
Code N-5
NAS, Pensacola, FL 32508
- 31 Dr. Alfred P. Smode
Training Analysis & Evaluation Group
(TAEG)
Dept. of the Navy
Orlando, FL 32813
- 32 Dr. Robert Wisher
Code 309
Navy Personnel R&D Center
San Diego, CA 92152
- 33 Mr John H. Wolfe
Code P310
U. S. Navy Personnel Research and
Development Center
San Diego, CA 92152

DEPARTMENT OF THE ARMY

- 34 Technical Director
U. S. Army Research Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333
- 35 HQ USAREUR & 7th Army
CDCSOPS
USA&EURE Director of GED
APO New York 09403
- 36 Dr. Ralph Eusek
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

- 37 Dr. Michael Kaplan
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333
- 38 Dr. Milton S. Katz
Training Technical Area
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333
- 39 Dr. Harold F. O'Neil, Jr.
Attn: PERI-OK
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333
- 40 Dr. Robert Sasnow
U. S. Army Research Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333
- 41 Dr. Joseph Ward
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

DEPARTMENT OF THE AIR FORCE

- 42 Dr. Earl A. Alluisi
HQ, AFHRL (AFSC)
Brooks AFB, TX 78235
- 43 Dr. Genevieve Haddad
Program Manager
Life Sciences Directorate
AFOSR
Bolling AFB, DC 20332
- 44 Dr. Marty Rockway (AFHRL/TT)
Lowry AFB
Colorado 80230
- 45 3700 TCHTW/TTGH Stop 32
Sheppard AFB, TX 76311 2
- 46 Jack A. Thorpe, Maj., USAF
Naval War College
Providence, RI 02846

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MARINE CCBPS

- 47 H. William Greenup
Education Advisor (E031)
Education Center, NCDEC
Quantico, VA 22134
- 48 Headquarters, U. S. Marine Corps
Code MPI-20
Washington, DC 20380
- 49 Special Assistant for Marine
Corps Matters
Code 100M
Office of Naval Research
800 N. Quincy St.
Arlington, VA 22217
- 50 Dr. A.L. Slafkosky
Scientific Advisor (CODE RD-1)
HQ, U.S. Marine Corps
Washington, DC 20380

COAST GUARD

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U. S. Coast Guard (G-P-1/2/TP42)
Washington, DC 20593

OTHER DEPARTMENT OF DEFENSE

- 52 Defense Documentation Center 12
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- 53 Dr. Dexter Fletcher
Defense Advanced Research
Projects Agency
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Arlington, VA 22209
- 54 Military Assistant for Training and
Personnel Technology
Office of the Under Secretary of Def
for Research & Engineering
Room 3E129, The Pentagon
Washington, DC 20301 Civil Govt

- 55 Dr. Susan Chipman
Learning and Development
National Institute of Education
1200 19th Street NW
Washington, DC 20208
- 56 Dr. Joseph I. Lipson
SEDRB W-638
National Science Foundation
Washington, DC 20550
- 57 Dr. Andrew R. Molnar
Science Education Dev.
and Research
National Science Foundation
Washington, DC 20550
- 58 Dr. Frank Withrow
U. S. Office of Education
400 Maryland Ave. SW
Washington, DC 20202
- 59 Dr. Joseph L. Young, Director
Memory & Cognitive Processes
National Science Foundation
Washington, DC 20550
- 60 Dr. John B. Anderson
Department of Psychology
Carnegie Mellon University
Pittsburgh, PA 15213
- 61 Dr. John Annett
Department of Psychology
University of Warwick
Coventry CV4 7AL
ENGLAND
- 62 Dr. Michael Atwood
Science Applications Institute
40 Denver Tech. Center West
7935 E. Prentice Avenue
Englewood, CO 80110
- 63 Psychological Research Unit
Dept. of Defense (Army Office)
Campbell Park Offices
Canberra ACT 2600, Australia

- 64 Dr. Alan Baddeley
Medical Research Council
Applied Psychology Unit
15 Chaucer Road
Cambridge CB2 2EP
ENGLAND
- 65 Dr. Patricia Baggett
Department of Psychology
University of Denver
University Park
Denver, CO 80208
- 66 Mr Avron Barr
Department of Computer Science
Stanford University
Stanford, CA 94305
- 67 Dr. Nicholas A. Bond
Dept. of Psychology
Sacramento State College
600 Jay Street
Sacramento, CA 95819 Non Govt
- 68 Dr. Lyle Bourne
Department of Psychology
University of Colorado
Boulder, CO 80309
- 69 Dr. John S. Brown
XEROX Palo Alto Research Center
3333 Coyote Road
Palo Alto, CA 94304
- 70 Dr. Bruce Buchanan
Department of Computer Science
Stanford University
Stanford, CA 94305
- 71 Dr. C. Victor Bunderson
WIC&I INC.
University Plaza, Suite 10
1160 SO. State St.
Orem, UT 84057
- 72 Dr. Pat Carpenter
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

- 73 Dr. John E. Carroll
Psychometric Lab
Univ. of No. Carolina
Davie Hall 013A
Chapel Hill, NC 27514
- 74 Charles Myers Library
Livingstone House
Livingstone Road
Stratford
London E15 2LJ
ENGLAND
- 75 Dr. William Chase
Department of Psychology
Carnegie Mellon University
Pittsburgh, PA 15213
- 76 Dr. Micheline Chi
Learning R & D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213
- 77 Dr. William Clancey
Department of Computer Science
Stanford University
Stanford, CA 94305
- 78 Dr. Allan M. Collins
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, Ma 02138
- 79 Dr. Lynn A. Cooper
Department of psychology
Uris Hall
Cornell University
Ithaca, NY 14850
- 80 Dr. Meredith P. Crawford
American Psychological Association
1200 17th Street, N.W.
Washington, DC 20036
- 81 Dr. Kenneth B. Cross
Anacapa Sciences, Inc.
P.O. Drawer Q
Santa Barbara, CA 93102

- 82 Dr. Hubert Dreyfus
Department of Philosophy
University of California
Berkeley, CA 94720
- 83 LCOL J. C. Eggenberger
Directorate Of Personnel Applied
Research
National Defence HQ
101 Colonel by Drive
Ottawa, CANADA K1A 0K2
- 84 Dr. Ed Feigenbaum
Department of Computer Science
Stanford University
Stanford, CA 94305
- 85 Mr. Wallace Feurzeig
Bolt Beranek & Newman, Inc.
50 Moulton St.
Cambridge, MA 02138
- 86 Dr. Edwin A. Fleishman
Advanced Research Resources Organ.
Suite 900
4330 East West Highway
Washington, DC 20014
- 87 Dr. John B. Frederiksen
Bolt Beranek & Newman
50 Moulton Street
Cambridge, MA 02138
- 88 Dr. Alinda Friedman
Department of Psychology
University of Alberta
Edmonton, Alberta
CANADA T6G 2E9
- 89 Dr. R. Edward Geiselman
Department of Psychology
University of California
Los Angeles, CA 90024
- 90 DR. ROBERT GLASER
LRDC
UNIVERSITY OF PITTSBURGH
3939 O'HABA STREET
PITTSBURGH, PA 15213

- 91 Dr. Marvin D. Glock
217 Stone Hall
Cornell University
Ithaca, NY 14853
- 92 Dr. Daniel Gopher
Industrial & Management Engineering
Technion-Israel Institute of
Technology
Haifa
ISRAEL
- 93 DR. JAMES G. GREENO
LRDC
UNIVERSITY OF PITTSBURGH
3939 O'HARA STREET
PITTSBURGH, PA 15213
- 94 Dr. James R. Hoffman
Department of Psychology
University of Delaware
Newark, DE 19711
- 95 Glenda Greenwald, Ed.
"Human Intelligence Newsletter"
F. C. Box 1163
Birmingham, MI 48012
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HUMBBQ/Western Division
27857 Berwick Drive
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- 97 Dr. Earl Hunt
Dept. of Psychology
University of Washington
Seattle, WA 98105
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LAWRENCE JOHNSON & ASSOC., INC.
Suite 103
4545 42nd Street, N.W.
Washington, DC 20016
- 99 Journal Supplement Abstract
Service
American Psychological Association
1200 17th Street N.W.
Washington, DC 20036

- 100 Dr. Steven W. Keele
Dept. of Psychology
University of Oregon
Eugene, OR 97403
- 101 Dr. Walter Kintsch
Department of Psychology
University of Colorado
Boulder, CO 80302
- 102 Dr. David Kieras
Department of Psychology
University of Arizona
Tucson, AZ 85721
- 103 Dr. Kenneth A. Livingston
Program Officer
Alfred P. Sloan Foundation
630 Fifth Avenue
New York, NY 10111
- 104 Dr. Stephen Kosslyn
Harvard University
Department of Psychology
33 Kirkland Street
Cambridge, MA 02138
- 105 Mr. Marlin Kroger
1117 Via Goleta
Palos Verdes Estates, CA 90274
- 106 Dr. Jill Larkin
Department of Psychology
Carnegie Mellon University
Pittsburgh, PA 15213
- 107 Dr. Alan Lesgold
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260
- 108 Dr. Michael Levine
210 Education Building
University of Illinois
Champaign, IL 61920

- 109 Dr. Robert A. Levit
Director, Behavioral Sciences
The BEM Corporation
7915 Jones Branch Drive
McLean, VA 22101
- 110 Dr. Charles Lewis
Faculteit Sociale Wetenschappen
Rijksuniversiteit Groningen
Cude Boterwegestraat
Groningen
NETHERLANDS
- 111 Dr. Mark Miller
Computer Science Laboratory
Texas Instruments, Inc.
Mail Station 371, P.O. Box 225936
Dallas, TX 75265
- 112 Dr. Allen Munro
Behavioral Technology Laboratories
1845 Elena Ave., Fourth Floor
Redondo Beach, CA 90277
- 113 Dr. Donald A. Norman
Dept. of Psychology C-009
Univ. of California, San Diego
La Jolla, CA 92093
- 114 Dr. Seymour A. Papert
Massachusetts Inst. of Technology
Artificial Intelligence Lab
545 Technology Square
Cambridge, MA 02139
- 115 MR. LUIGI PETRULLO
2431 N. EDGEWOOD STREET
ARLINGTON, VA 22207
- 116 Dr. Martha Polson
Department of Psychology
University of Colorado
Boulder, CO 80302
- 117 DR. PETER POLSON
DEPT. OF PSYCHOLOGY
UNIVERSITY OF COLORADO
BOULDER, CO 80309

118 DR. CLAIRE M. RAMSEY-KLEE
R-K RESEARCH & SYSTEM DESIGN
3947 RIDGEMONT DRIVE
MALIBU, CA 90265

119 Dr. Fred Reif
SESAME
c/o Physics Department
University of California
Berkeley, CA 94720

120 Dr. Andrew M. Rose
American Institutes for Research
1055 Thomas Jefferson St. NW
Washington, DC 20007

121 Dr. Ernst Z. Rothkopf
Bell Laboratories
600 Mountain Avenue
Murray Hill, NJ 07974

122 DR. WALTER SCHNEIDER
DEPT. OF PSYCHOLOGY
UNIVERSITY OF ILLINOIS
CHAMPAIGN, IL 61820

123 Dr. Alan Schoenfeld
Department of Mathematics
Hamilton College
Clinton, NY 13323

124 Committee on Cognitive Research
c/o Dr. Lonnie B. Sherrod
Social Science Research Council
605 Third Avenue
New York, NY 10016

125 DR. Robert Smith
Department of Computer Science
Rutgers University
New Brunswick, NJ 08903

126 Dr. Richard Snow
School of Education
Stanford University
Stanford, CA 94305

- 127 Dr. Kathryn T. Spoehr
Department of Psychology
Brown University
Providence, RI 02912
- 128 Dr. Robert Sternberg
Dept. of Psychology
Yale University
Box 11A, Yale Station
New Haven, CT 06520
- 129 DR. ALBERT STEVENS
BOLT BERANEK & NEWMAN, INC.
50 SCULTON STREET
CAMBRIDGE, MA 02138
- 130 Dr. David Stone
ED 236
SUNY, Albany
Albany, NY 12222
- 131 DR. PATRICK SUPPES
INSTITUTE FOR MATHEMATICAL
STUDIES IN THE SOCIAL SCIENCES
STANFORD UNIVERSITY
STANFORD, CA 94305
- 132 Dr. Kikumi Tatsooka
Computer Based Education Research
Laboratory
252 Engineering Research Laboratory
University of Illinois
Urbana, IL 61801
- 133 Dr. John Thomas
IBM Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10599
- 134 Dr. Douglas Towne
Univ. of So. California
Behavioral Technology Labs
1945 S. Elena Ave.
Redondo Beach, CA 90277
- 135 Dr. Benton J. Underwood
Dept. of Psychology
Northwestern University
Evanston, IL 60201

- 136 DR. THOMAS WALLSTEN
PSYCHOMETRIC LABORATORY
DAVIS HALL 013A
UNIVERSITY OF NORTH CAROLINA
CHAPEL HILL, NC 27514
- 137 Dr. Phyllis Weaver
Graduate School of Education
Harvard University
200 Larsen Hall, Appian Way
Cambridge, MA 02138
- 138 Dr. David J. Weiss
M66C Elliott Hall
University of Minnesota
75 E. River Road
Minneapolis, MN 55455
- 139 DR. GERSHON WELTMAN
PERCEPTONICS INC.
6271 VARIEL AVE.
WCOULD HILLS, CA 91367

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